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Review

Marine fisheries enhancement in New Zealand: our perspective

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Abstract Increasing human population and its demand for fishery products is placing mounting pressure on the coastal marine environment. As wild fisheries reduce in size or stabilise there is growing interest in enhancement as a means of restoring or increasing production. The purpose of this paper is to document marine enhancement initiatives in New Zealand and to describe species, or groups of species, of potential enhancement interest over the next 10 years. An overview of any potentially negative impacts of such enhancements is given. The rise in interest in fisheries enhancement in New Zealand in recent years, which is likely to further increase in coming years, flows from the successful Nelson scallop enhancement programme, encouraging results from other initiatives, and the growing momentum of marine enhancement internationally. However, there is also an increasing awareness that stocking alone is seldom enough, and that successful enhancement often requires restoration of key components of the marine environment itself. The species likely to be of most interest for enhancement in New Zealand over the next 10 years are scallops, dredge oysters, estuarine shellfish including cockles and pipi, toheroa, paua, rock lobster, certain seaweeds, snapper, and salmon. There will probably also be interest in the wider use of artificial reefs for ecosystem development. Such initiatives could potentially take place the length and breadth of the country, to the benefit (or cost) of all users, commercial, recreational, and customary. They will bring new challenges to managers of marine resources as demands for more localised management intensify.

Keywords enhancement; fisheries; marine; New Zealand; outplanting; seeding; stocking

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INTRODUCTION

The growing demand for fishery products is placing mounting pressure on the coastal marine environment. As wild fisheries reduce in size or stabilise there is growing interest in enhancement strategies as a means of restoring or increasing production. Stocking of coastal fisheries has now been attempted, at some level, for more than 100 species in over 25 countries (Bartley 1999; Liao 1999; also see enhancement websites given in Anon. 2001a). New Zealand is one such country. However, there is also growing recognition that stocking alone is seldom enough to produce greater sustainable yields and that successful enhancement often requires restoration of key biological components of the marine environment itself, particularly the structural complexity and biodiversity of the sea floor.

Defining enhancement

Enhancement is not the same as aquaculture. Enhancement involves manipulation of the physical or biotic environment to increase harvests, and/or supplementing natural recruitment by introducing new stock. Aquaculture on the other hand involves either the culture of a species on land or in the sea in a controlled or semi-controlled environment, or the ongrowing in captivity of a species from an early life-history stage. Examples of aquacultured species in New Zealand include Pacific oysters (*Crassostrea* *gigas*) and green-lipped mussels (*Perna canaliculus*) (Holland & Jeffs 2000). Nevertheless, enhancement and aquaculture can be complementary. This is particularly so where seed are produced in hatcheries for outplanting but also, for example, where the breeding of an aquacultured species enhances populations of nearby wild stocks of that species.

We use the term enhancement broadly, to encompass the practices of: (1) releasing the early life-history stages of an animal or plant into natural or modified habitats; (2) transferring animals or plants from one habitat to another; and (3) modifying the wild habitat to make better use of natural or introduced seed. Similar terms used to describe the first two include sea (marine) ranching, stocking, planting, outplanting, seeding, and re-seeding. The focus of the third enhancement practice is the marine environment itself. It may, for example, involve restoration—direct intervention to re-establish a species, community, or ecosystem in an area where it used to be important but has declined in quality or quantity due to natural or human-induced disturbances.

These are not, however, the only techniques of stock enhancement. Fisheries may also be enhanced through such management measures as reducing fishing pressure, reducing catches, applying minimum and/or maximum legal sizes, and applying area closures (e.g., see Babcock et al. 1999) or other restrictions on access or activity, but these are not considered here in any detail. Other techniques, also not specifically addressed because they are not likely to be relevant to New Zealand, include: (1) introducing new species to exploit under-utilised parts of the food chain or habitats not colonised by the resident fauna or flora; (2) developing an artificial fauna or flora of selected species to increase the degree of control and the yield of the system; and (3) modifying water bodies by cutting off bays and arms as culture ponds.

Benefits and risks of enhancement

Enhancing coastal species has the potential to increase yields, rebuild overexploited stocks, and dampen fluctuations in catch because of variable recruitment. However, despite many initiatives worldwide, little rigorous documentation of the impact of marine enhancement programmes has been undertaken (Welcomme & Bartley 1998) and many questions remain about their economic and ecological soundness (Munro & Bell 1997; Travis et al. 1998). Indeed, many initiatives may be economic failures (for examples, see Hilborn 1998), often because the enhancement method used has been inappropriate (Blankenship & Leber 1997). In light of concerns that marine stocking is not cost-effective, and may even endanger wild resources, prediction of the success of ventures is increasingly being demanded by investors and fishery managers. Often success centres on whether or not a particular programme is actually enhancing the abundance of the target species or is simply concentrating its numbers (see Lindberg 1997; Bohnsack et al. 1997; Pickering & Whitmarsh 1997 for discussion). Furthermore, there is a view that enhancement is fully effective only when it leads to a growing population of the target species, rather than when a "put and take" programme is established whereby individuals are transplanted into depleted areas and harvested some time later (Turner et al. 1998).

Negative impacts of enhancement can include transmission of disease and pests, habitat disturbance, rampant increase in abundance, loss of ecological balance, increased numbers of predators, reduced numbers or size of individuals in the wild stock, elimination of species and loss of diversity, reduced genetic heterozygosity, and insufficient primary production to support enhanced populations. However, precise assessment of such impacts is almost always extremely difficult. The genetic consequences of enhancement, particularly where there is translocation of stock, is of particular concern. Although large-scale transplants might have positive benefit by producing particularly well-adapted offspring, we did not find any genetic literature that supported them except when there was thorough knowledge of stock structure. Where there is deep genetic structure, indicating substantial evolutionary independence of sets of populations, translocation may threaten genetic diversity (Johnson 2000). Stocking may also result in hybridisation with related species or with endemic populations of the same species (Cross 2000; Doupé & Lymbery 2000), with any transgenic organisms that end up displaying dramatically novel but ecologically competent traits being of particular concern (Kapuscinski & Brister 2001).

History of marine fisheries enhancement in New Zealand

Maori practiced enhancement as part of their traditional management of kai moana (seafood) and other things precious. They took seriously the responsibilities and obligations of kaitiakitanga (decision-making authority), involving respect and the duty to take good care of these marine resources (Best 1929). Thus overfishing would have been viewed as negative and the enhancement of stocks positive. Fishing and any other interactions with the natural environment by iwi (tribes) and hapu (families) in their rohe (areas of management and control) were apparently carefully controlled according to tikanga. Tikanga is a complex framework of practical management rules, ritual, and protocol, recognising the metaphysical dimension as well as the ecological, working to protect the mauri (life force) of each resource as well as to sustain its physical viability (Office of the Parliamentary Commissioner for the Environment 1999). Techniques intended to enhance the state of fisheries included transplanting shellfish from one location to another, seeding new varieties, and assisting the rebuild of depleted stocks. Fishers would sometimes target predators, for example to help shellfish repopulate. Shellfish managed in this way included mussels (*Perna canaliculus* and *Mytilus galloprovincialis*), cockles (*Austrovenus stutchburyi*), scallops (*Pecten novaezelandiae*), tuatua (*Paphies donacina* and *P. subtriangulata*), toheroa (*P. ventricosa*), and pipi (*P. australis*) (Habib 1989). However, the tikanga seems to exist more in local oral tradition than in written form and so detailed descriptions of the practices are not possible.

The earliest attempts at marine enhancement in New Zealand in European times took place in the late 19th and early 20th centuries when fertilised herring ova (*Clupea harengus*), young turbot (*Scophthalmus maximus*), crabs (*Cancer pagurus*), and lobsters (*Homarus gammarus*) were transported in batches from Europe (Thomson & Anderton 1921). Ponds and hatchery were established for them at Portobello on Otago Harbour, and releases of young made locally into the wild. None survived. In the early 1930s, rock beds for rock oyster (*Saccostrea commercialis glomerata*) settlement were established in northern harbours (Curtin 1972). Concurrently, spat collectors were set, weed and other epiphytes cleared from rock surfaces to permit spat settlement, and predators destroyed (Waugh 1973). At the other end of the country, in the Foveaux Strait dredge oyster (*Tiostrea chilensis*) fishery, an experiment in the early 1970s showed the benefit of returning shell to specific areas of oyster bed. Not only did some of the small, newly settled oysters on host shells survive, but the host shells themselves were soon colonised by new oysters (Street et al. 1973). Research into dredge oyster enhancement, as described below, continues.

During the last quarter of the 20th century the main emphasis of enhancement activities centred on small-scale experiments to enhance populations of estuarine shellfish (e.g., cockles) and paua (*Haliotis iris*). But also during this time were developed the first demonstrably successful marine enhancement programmes in New Zealand—for scallops in Tasman and Golden Bays, and salmon (*Oncorhynchus tshawytscha*) in Otago Harbour.

Scope of this review

The purpose of this review is to describe the marine fisheries enhancements attempted in New Zealand and, with a 10-year horizon, to comment on the species and groups of species of potential enhancement interest. We examined both the published and grey literature, and consulted industry and colleagues throughout the country. We looked into fisheries enhancement developments elsewhere that might also take place in New Zealand. Species most likely to be the subject of enhancement initiatives in New Zealand are those that have been heavily fished, have decreased in abundance through pollution, whose habitat has been damaged or destroyed, or those for which habitat expansion might lead to increased production. The areas (refer to Fig. 1) where enhancement might take place are discussed (although we take no account of legal or other constraints imposed by legislation administered by central or local government). We also discuss the broader approaches of developing artificial reefs and fertilising the sea to promote production. Any potentially worrisome impacts of such enhancements, and associated planning and legislative issues, are broadly reviewed.

CURRENT AND POTENTIAL SPECIES FOR ENHANCEMENT IN NEW ZEALAND

Scallops

The scallop (*P. novaezelandiae*) fishery, mainly in the Nelson region's Tasman and Golden Bays and based on both natural seed as well as re-laid wild-caught scallop spat, is one of the most notable enhanced scallop fisheries anywhere. There is typically very changeable wild scallop recruitment from year to year because of high variability in the mortality of the early life stages. This results in fluctuations in recruited biomass, especially in areas of rapid growth where there may be only one or two recruited year classes. Enhancement has helped raise and stabilise production. The Challenger Scallop Enhancement Company employs the dual strategy of catching spat within collector bags, along with

Fig. 1 Map of New Zealand showing places mentioned in text.

dredging and transplanting juvenile scallops that have fallen from the outside of the collector bags (Bull 1994; Arbuckle & Metzger 2000). There are eight authorised spat-catching sites in Tasman and Golden Bays and usually one of these from each bay is used each year. The longline bags provide settlement surfaces for the postlarvae, allowing them to grow large enough (15–30 mm diam.) to survive on the sea floor. They are then stripped from the longlines and spread over suitable areas from a moving vessel.

The enhanced scallop fishery is operated on a rotational basis, taking 3 years for the young scallops to reach harvestable size. It was estimated that 40–50% of the 1992 landings of c. 700 t meat weight came from seeded origin (Bull 1994). The 1999 biomass survey pointed to the fourth largest commercial harvest in the 40-year history of the fishery, with a resulting 676 t of product (Arbuckle & Metzger 2000). The enhanced scallop populations also bring about increased natural spat settlement on the sea floor. While the enhancement is undertaken by the quota holders, recreational fishers and iwi also have access to the enhanced grounds.

The success of the Tasman and Golden Bays scallop enhancement is in large part attributable to the crucial role of the spat settlement longlines that provide surrogate natural settlement surfaces. Further production from this fishery may lie in restoring the seabed, as there is increasing evidence that the nature of the sea floor ultimately determines scallop survival and levels of production. Scallops live on substrates with a predominant cover of sand and mud, most commonly at depths of 10–30 m. It appears that dredging has significantly altered the nature of the seabed in places (Tunbridge 1968). This disturbance is thought to have contributed to declines in natural settlement and spat survival. The return of processed shell is under discussion as a contribution toward seabed restoration.

Techniques established in Tasman and Golden Bays are probably applicable to all New Zealand scallop fisheries. These are distributed throughout the country, with the most important commercial fisheries outside Nelson being off Northland and the Coromandel Peninsula. During the 1980s, spat were successfully caught in both regions, but there was high mortality among the re-laid shellfish (Bartrom 1991). Highly variable spatfalls and low survival of seeded spat have continued to hamper these trials (Nesbit 1999). Within the next 10 years it is likely there will be further enhancement trials outside Nelson. However, because of variable spat catches in several parts of the country, it is possible that spat will also be sought from Tasman and Golden Bays.

Dredge oyster

The Bluff Oyster Management (previously Enhancement) Company settled eye-spotted *T. chilensis* larvae from dredged wild adults on weathered oyster shell in shore-based tanks (Street 1995; The Bluff Oyster Enhancement Company 1995). These were ongrown for varying periods before release on selected areas of the Foveaux Strait oyster bed. In 1995, most of the oysters were being laid in statistical area A, the old East Bed, a once productive area that had been fished down. The enhancement of deeper (20–50 m) sites in Foveaux Strait and adjoining coasts was also tried, but not all experiments showed good survival (Keogh et al. 1997). Promising indications for successful enhancement are now emerging from ongoing trials in which wild spat and spat settled from spawned captive oysters have been ongrown to 30 mm shell diameter in nursery areas and then laid out on commercial beds as single seed oysters (R. J. Street, 7 Gala St, Dunedin pers. comm.). In Chile this species is cultured onshore (Aiken 1993; Jeffs & Creese 1996), so the potential also exists in New Zealand for hatchery-produced larvae and seed oysters to be used to enhance natural beds.

There is growing awareness, however, that enhancement of this shellfish in Foveaux Strait may benefit from, if not require, restoration of their epifaunal reefs (Cranfield et al. 1999, 2001). Commercial densities of oysters often occur on these bryozoan-dominated reefs, where natural mortality is probably lower, recruitment higher, and growth faster than on other substrates. Heavy fishing, often with weighty dredges, destroys these reefs, but reef restoration may be possible through appropriately returned shell (Cranfield et al. 1999). Further, recent trials of returned shell with young oysters attached proved successful in establishing a reef and in enhancing oyster density (Cranfield et al. 2001; Cranfield & Michael 2002). Enhancement of the Foveaux Strait oyster fishery and restoration of the beds is therefore likely to involve several procedures: the spreading of seed oysters, attempts at reef restoration including more focused distribution of shell, and possibly the development of more benign harvesting methods such as using lighter, less destructive dredges. Further, a rotational fishing strategy that fishes specific enhanced sites only when the oysters have attained marketable size would maintain a higher diversity in sea floor habitat than if fishing was continuous (Cranfield & Michael 2002).

The benefits that may eventually accrue from oyster seeding and reef restoration in Foveaux Strait are also possible for the Nelson region, the other major area where this oyster occurs, even though the seabed is more muddy. The Challenger Dredge Oyster Fishery Management Company is investigating oyster enhancement in Tasman and Golden Bays (Arbuckle & Metzger 2000), based largely on the Foveaux Strait methods. The trials are jointly managed with the scallop enhancement and dredging programmes.

The dredge oyster is widespread and seeding is therefore possible in other parts of the country (Jeffs et al. 1997). The collection of spat at one site and their transfer to another for outplanting is likely.

Estuarine shellfish

Many estuaries in New Zealand have been adversely affected by human activity. Shellfish beds in particular have become degraded through such things as over-harvesting and sediment run-off from eroding farmland and deforestation of catchment areas. Affected New Zealand species—important to both customary and recreational fishers—include cockles (*A. stutchburyi*) and pipi (*P. australis*), and the mud snail (*Amphibola crenata*).

Enhancement can be achieved through the seeding of shellfish beds with hatchery-produced or wild-caught spat (Stewart & Creese 1998). In the mid-1990s a 3-year project to assist local people re-establish and augment cockle beds in Raglan Harbour was developed, based on hatchery-produced spat ongrown in cages, with good resulting survival (National Institute of Water and Atmospheric Research Limited unpubl. data). This work led to the formulation of guidelines on the planning, legal, and procedural requirements necessary before implementing restoration and enhancement projects (Turner et al. 1998). Although we know of no attempts to collect and transfer naturally settled cockle spat, Stewart & Creese (2002) transplanted both juvenile and adult cockles and concluded that transplanting was feasible and would be particularly successful for adults.

Probably the most widespread customary enhancement currently undertaken is shellfish transplants (particularly cockle) from natural beds to areas of low abundance and/or better growth (Ministry for Maori Development 1993). Transferrals most commonly take place over short distances such as within harbours, because there is often cultural concern about moving stock or spat between distant locations. However, we found nothing published on the extent or outcomes of this practice.

Beds of cockles and pipi, which occur around the country, might therefore be enhanced either by translocating shellfish from natural beds or by seeding with hatchery or natural spat. Elsewhere, particularly in North America, estuarine bivalve populations are widely enhanced, often very successfully, through outplanting hatchery-produced spat (for examples, see abstracts from the "International Conference on Shellfish Restoration", and papers in *Journal of Shellfish Research 17*, 1998) and naturally settled spat (e.g., Mottet 1985; Chandler et al. 2001). In New Zealand, urban beaches are a likely focus in the near future. One such beach is Cheltenham Beach in Auckland, where recreational harvesting has apparently contributed to the near obliteration of what were once large populations of cockles and pipi (Morrison & Browne 1999). The deepwater clam (geoduc) *Panopea zelandica*, experimentally fished for several years in Golden Bay (Breen 1994), is also likely to be of interest through the seeding of hatchery spat. Geoduc enhancement is practiced in North America where hatchery spat are contained and grown within plastic tubes set in the wild (Poole 1998).

Toheroa and other surfclams

Some beds of the more open coast shellfish species have been heavily fished, but overall these bivalves have been less affected by human activity than the estuarine ones. A suite of surfclam species live from low water to 10 m depth (Cranfield et al. 1994), each species being abundant over a distinct depth range that generally overlaps little with that of other species. Most surfclam fishing is recreational and customary, with only limited commercial harvesting being undertaken in recent years, using lightweight hydraulic dredges.

Toheroa (*P. ventricosa*) is the surfclam species most likely to be the subject of enhancement initiatives over the next 10 years. Hapu on the west coast of Northland have transferred toheroa from beaches with high abundance to ones with low numbers for many years, apparently with success (Akroyd 2002). This bivalve is found near low water level intermittently throughout the country, but particularly on west coast beaches of the North Island and in Te Waewae Bay and Oreti Beach in western Foveaux Strait. The spat appear to settle high on the beach and later move down to near low water level. Changes in abundance of this shellfish over time may be related as much to natural phenomena as fishing pressure (Tunbridge 1967; Redfearn 1974; Akroyd 2002), with marked changes in distribution and abundance happening for unknown reasons. However, vehicles driven along toheroa beaches have been found to cause spat mortality (Hooker & Redfearn 1998), so enhancement might take the form of restrictions on use, particularly of motorcycles (Akroyd 2002). There could also be seeding of hatchery spat (which have been produced—Redfearn 1982), as quite widely practiced overseas (see *Journal of Shellfish Research 17*, 1998), possibly using protective structures for the first few weeks of growth. Transferrals of toheroa from one bed to another are also likely to take place, particularly where there has been high recruitment on the supply beach. Experimental transfer of toheroa among west coast Northland beaches gave encouraging results (Akroyd 2002).

Mussels

Both blue (*Mytilus galloprovincialis*) and green-lipped (*Perna canaliculus*) mussels are widely taken recreationally and in customary fishing. Green-lipped mussels are also the basis of a huge longline aquaculture industry (Holland & Jeffs 2000), the large-scale transfer of spat from Ninety Mile Beach to the farms of Marlborough Sounds presumably also leading to enhanced local settlement near the farms.

Mussel enhancement is most likely to take place on a small scale, particularly by hapu managing their valued beds. Natural and artificial settlement surfaces to collect spat have been studied (e.g., Manning 1985), fibre thickness and the ability to protect the young mussels from desiccation being important factors in their success. There have been proposals to seed parts of the Hokianga Harbour and central Bay of Plenty (Jeffs 1995), involving placing seaweed encrusted with *Perna* spat directly on the seabed, sometimes held down with fine mesh. Additionally, some hapu apparently remove large individual *Perna* from beds to promote the growth of smaller ones.

Paua

New Zealand abalone harvested from wild stocks form valuable commercial, recreational, customary, and illegal (mainly shellfish taken for sale outside of quota) fisheries. The most important species is the black-footed paua *Haliotis iris*. Nevertheless, the yellow-foot paua *H. australis* appears to grow as fast as *H. iris* and may be more valuable (McShane 1995). Both species are also grown commercially, on a small scale, in New Zealand (Tong & Moss 1992; Holland & Jeffs 2000).

Enhancement of *H. iris* can be achieved through several means, the first being outplanting of hatchery seed. Seeding of abalone can be with larvae or small juveniles (shells 5–10 mm long), the variable success of which was reviewed by McCormick et al. (1994). In New Zealand, Tong et al. (1987) tried seeding larvae near Wellington with some success but, in later more intensive trials, survival was low (Schiel 1989, 1992). Habitat surveys and reseeding studies near Auckland found that the optimum habitat for juveniles was within pebble or cobblestone substrates under layers of boulders in areas with moderate water circulation (Osumi 1999; Clarke 2001). Cultured paua did not survive as well as wild ones when seeded and in general, small paua raised in dark environments were the most suitable to seed. A commercial-scale trial at the Chatham Islands using 3–30-mm-long paua showed that there would be an economic return of legal-sized paua at some sites (Schiel 1993). McShane (1995), however, concluded that enhancement would probably be effective only in areas depleted of paua or with little recruitment. He argued that reseeding larvae, late stage juveniles, or adults was unlikely ever to be economic and that sea farming had more potential: provision of artificial reef, predator control, and parallel farming of seaweed food. Nevertheless, a trial is underway at Stewart Island using seed c. 9 mm long (Anon. 2002; Naylor 2002) as part of a larger proposal by local paua quota holders to augment paua stocks (The New Zealand Paua Management Company 2000). Similar initiatives are likely in other major paua areas, which are mostly in southern waters. Probably the only other clients for hatchery seed for release into the wild will be hapu with traditionally important reefs in need of restocking.

The next method of paua enhancement is moving stunted or overcrowded stocks to areas with better growth. Several populations of *H. iris*, particularly in Northland, Taranaki, and parts of Banks Peninsula, appear seldom to reach minimum legal size (125 mm shell length). Tagging has shown that, at least in Taranaki and Banks Peninsula, growth is different to that in other parts of the country, and different minimum legal sizes might be appropriate (Naylor & Andrew 2001). Nevertheless, transfers from such areas, and from places where densities are very high, are likely on only a small scale because of the cost and uncertain outcome.

A third method is to relocate dislodged paua. Live paua are cast up on sandy shores from time to time, particularly on the east coast of the North Island. These are thought to be paua from reefs inundated with sand—traditionally Maori returned such shellfish to nearby reefs. A study with iwi at Aohanga in the Wairarapa seeks to determine the survival of returned paua and how survival varies with distance from a river mouth (Notman & Naylor 2000). At Kaikoura, paua are moved to other rocks when in danger of being covered by sand (Ministry for Maori Development 1993).

The next method is to transplant brood stock. Fertilisation success in abalone appears to be dependent on the distances separating individuals (Babcock & Keesing 1999; Roberts et al. 1999), and settlement is probably derived from nearby adults because larval dispersal is thought to be localised (McShane et al. 1988). Therefore, at very low abalone destiny, natural recovery may not take place. Experiments in California in the early 1970s suggested that establishing higher densities of brood stock might be an effective, if expensive, way to rebuild abalone stocks (Tegner 1992). Although unlikely because of the high cost and unsure outcome, its application in New Zealand cannot be ruled out.

The fifth method of paua enhancement is the use of artificial reefs. These are used in abalone enhancement in Japan with mixed results, but McShane (1995) considers that they do have potential in New Zealand. Aggregations of such items as boulders and concrete blocks would bring protection to paua introduced as young juveniles. In the one local trial known about, Mercer (1986) released 15–40-mm-long paua into clay field pipe reefs in the Marlborough Sounds and found high growth and survival over the first few months. However there was high mortality and slow growth after 6 months, probably because of sanding-up. Sand movement and sedimentation are probably the greatest threats to the placement of reef structures for paua, together with colonisation by competing organisms.

The final enhancement technique is ecosystem modification. Paua and kina (the sea urchin *Evechinus chloroticus*) are herbivores occupying similar subtidal habitats. They are frequently found in close association, and at high densities appear to exclude each other (Roberts et al. 1999; Naylor & Gerring 2001). It may be possible to rehabilitate or enhance paua populations by removing kina from reefs grazed down by them before introducing paua. If ongoing trials (Naylor & Gerring 2001) are successful, these techniques could be considered for use in areas where paua are threatened by a kina population explosion.

Kina

Sea urchins form valuable fisheries in several parts of the world. Most of the fisheries are fully or over exploited and, at least in Japan, wild stocks are augmented through hatchery production (McShane 1997; Rogers-Bennett 2000; Anon. 2001a). There is one sea urchin in New Zealand of fisheries significance, the kina *E. chloroticus*. This species is widespread, in places abundant. It is of great significance to customary fishers, and heavily exploited in some local areas albeit lightly fished overall. Roe quality is the critical factor in the development of this fishery. An enhancement approach being contemplated is the removal of large urchins with their inferior roe, leaving small and mid-sized ones to harvest.

Enhancement strategies such as thinning, transplanting, seeding, providing refugia for settlers, and rotational harvesting may be tried in New Zealand as the value of this animal is realised (Mead 1996). Population enhancement strategies could target any of the life-history stages, events, or resources that can be limiting—including fertilisation rates, larval supply, juvenile survival, and food availability (Rogers-Bennett 2000). Unlike many species internationally, it appears that kina are capable of achieving high rates of fertilisation over quite large separation distances (c. 6 m), the minimum adult density required to achieve fertilisation success being calculated to be 0.33–0.67 m^{-2} (Mead 1996). Seeding of selected reefs with hatchery or wild-caught juveniles may be the approach most widely applied in the next 10 years.

Rock lobster

Of the two commercial palinurids in New Zealand, the only one likely to bear any enhancement initiatives in the near future is the red rock lobster, *Jasus edwardsii*. This is a very important species commercially, recreationally, and traditionally throughout the country. Seeding of hatchery pueruli is not an option at present, and is unlikely to be in the near future. *J. edwardsii* has a very long (at least 12 months) larval life and it is only recently that it has been grown through all its larval stages, and then in only small numbers. Wild-caught pueruli are a potential source of seed, but catching sufficient numbers for outplanting will probably always be too costly (Booth et al. 1999). In Australia, seeding trials with wild-caught *J. edwardsii* pueruli ongrown in captivity for 12 months are underway; some of these experiments are being conducted in New Zealand (Oliver et al. 2002; Stewart et al. 2002). Such lobsters —c. 30 mm in carapace length—would appear to be the most suitable for restocking, apparently retaining sufficiently their behavioural patterns and escape responses to survive in the wild (Kington 1999; Oliver et al. 2002).

The most successful enhancement technique practiced (and still only experimentally) for rock lobsters anywhere is the provision of artificial shelter for settling pueruli and for young juveniles. For *Panulirus argus* in the Caribbean, provision of simple shelters was shown to significantly increase juvenile survival and abundance (Butler & Herrnkind 1997; Herrnkind et al. 1997; Briones-Fourzan & Lozano-Alvarez 2001). Although larger artificial reefs have been installed in Japan to provide both settlement surfaces and habitat for larger lobsters, the efficacy of the approach remains unknown (Nonaka et al. 2000).

Enhancement of New Zealand *J. edwardsii* is being attempted in experiments designed to increase survival at settlement (Jeffs & Booth 2001). The trials hinge on the apparently low survival of pueruli as they change from a largely pelagic to a totally benthic existence, at which time they may experience a survival bottleneck through lack of shelter. The approach has been to test small, removable artificial shelters to enhance the survival of pueruli. Any enhancement success will probably be most relevant to small, local management areas, and in areas of high settlement (e.g., east coast of the North Island south of East Cape) where any survival bottleneck is probably most acute.

The transfer of juvenile or adult lobsters from one locality to another to rebuild stocks could take place anywhere, but is always likely to be small in scale because of the cost and unsure outcome.

Seaweeds

Seaweeds are not cultured or enhanced to any extent in New Zealand, but they are in many other countries such as Japan and Chile. New Zealand's marine flora of over 1000 species gives scope for many initiatives, about which it is impossible to be specific at this time. Any enhancement here is, however, likely to be modest in scale and scope, labour intensive and serving particular community needs, supplying small niche markets, or applied as restorative measures after such things as storm events.

Gracilaria spp. are red seaweeds with a long history of use as, *inter alia*, a source of the gelling phycocolloid, agar (Pickering 1989). There are three widespread species in mainland New Zealand (Adams 1994). They are most common in the intertidal and subtidal zones of sheltered coasts, harbours and estuaries, but also live on exposed coasts, sometimes subtidally. *Gracilaria* spp. can form vast meadows on mudflats, such as in Manukau Harbour, and are tolerant of silt and sand. *Gracilaria* can be farmed or else enhanced by providing hard surfaces such as rock and shell, broadcasting settled early life-history stages, and by securing whole plants. Many northern estuaries and embayments may be suitable for *Gracilaria* enhancement.

Pterocladia lucida and *P. capillacea* are also widespread agar red seaweeds. The most important, *P. lucida*, lives below low tide level on exposed shores (Adams 1994). It is the basis of a small handgathering industry, mainly along the coasts of Wairarapa, Hawke Bay, and Poverty Bay. Although not the subject of seeding or other such propagation, *P. lucida* production is influenced by the harvesting technique: when harvested in summer, plants recover to their initial biomass in 12 months, whereas plants harvested in winter recover much more slowly (Gerring et al. 2001).

Karengo, the widespread red seaweed *Porphyra* spp., is an important food in several rohe. It is found on upper intertidal rock in moderately sheltered to open sites (Adams 1994). The method of harvest has a major effect on regeneration: for example, regrowth has been found to be much greater when basal portions are left intact compared with when whole plants are removed (Nelson & Conroy 1989). Outplanting artificially raised early life-history stages to enhance local populations has been moderately successful at D'Urville Island (Alcock, NIWA pers. comm.).

Storm-damaged beds of *Macrocystis pyrifera*, an open coast brown alga occurring to 20 m depth and abundant south of Castlepoint, might be rehabilitated through outplanting substrate-attached germlings or young plants (e.g., Dean & Deysher 1994). Growth of other species may be enhanced through outplantings, providing particular substrates, or possibly by clearing substrates to enhance the target species.

To summarise, there is likely to be increased interest over the next 10 years in enhancing seaweed production by one or a combination of methods including manipulation of the sea floor, outplanting spores or young plants, and providing suitable substrates. This could take place anywhere around the country, but probably always on a small scale. The destruction of kelp beds in the course of coastal development may call for the construction of mitigating artificial reefs for seaweed growth (e.g., Ambrose 1994); artificial reefs are discussed later.

Snapper

The snapper *Pagrus auratus* is New Zealand's most important inshore finfish for commercial, recreational, and customary fishers and there has long been keen interest in its sustainability. A conference in 1982, "Prospects for snapper farming and reseeding in New Zealand", was aimed specifically at finding ways to maintain and, if possible, enhance wild populations. Successful, intensive culture techniques, based on both Japanese and European methods (Tait 1997), have been developed that can potentially provide seed fish. However, there is the view that the costs associated with any snapper enhancement of sufficient scale to have a significant impact on large fisheries such as that in the Hauraki Gulf will be unacceptably high. On the other hand, the lack of empirical data makes such a conclusion speculative.

Despite relatively straightforward hatchery production, there has not been release of snapper in

New Zealand to any significant level until very recently. Releases of 2000 juveniles weighing 300 g and 90 000 weighing c. 10 g into the Hauraki Gulf in May 2003 followed that of 4000, 200–350 g tagged snapper two months earlier (Anon. 2003). The releases are part of an enhancement programme aimed at enhancing localised areas of the gulf, particularly for recreational fishers. Further and larger-scale seeding could take place over the next 10 years, but attention is also on the juvenile habitat, some of which has been affected by trawling. Most trawling currently takes place outside the main areas of known remaining juvenile habitat, which appear to be mainly the shallow inshore reef and turf zones—but juvenile habitat may have been more diverse and widespread before trawling began. Water quality management, particularly in the tidal creeks that often contain small juvenile snapper, could also be crucial to the maintenance of juvenile snapper abundance.

Snapper are predominantly a northern New Zealand fish, the only significant stock in the South Island being in Tasman Bay and the Marlborough Sounds. Any enhancement of juvenile survival through seabed rehabilitation would be beneficial throughout its range. Seeding of hatchery fingerlings might take place in any of the main fishery areas, particularly in northern waters.

Salmon

There is a lot of interest in the release of juvenile chinook salmon (*O. tshawytscha*) into South Island harbours for recreational fishers. Some of the releases into Otago Harbour, made since the 1980s, have been very successful (Unwin et al 1991). There have also been unsuccessful releases in Lyttelton Harbour in 1989–90, several liberations into Bluff Harbour, and interest in releases into the Marlborough Sounds. For optimal survival the smolt are liberated as 15 cm-long yearlings weighing c. 50 g, and those that remain in the vicinity become available to anglers from c. 2 years of age.

It is likely that there will be continuing interest in smolt releases for as long as there are funds to cover their production. All semi-enclosed harbours and embayments of the east and south coasts of the South Island, and Stewart Island, wherever some of the released fish are likely to remain, are potential areas.

Other fishes

There have been informal suggestions of enhancement through the release of adults and/or hatchery fry of kingfish (*Seriola lalandii*) (see Poortenaar et al. 1999), flounders, and grey mullet (*Mugil cephalus*) into northern areas, and blue cod (*Parapercis colias*) into the Marlborough Sounds. Flounders of the genus *Rhombosolea* have been cultured to juvenile (Hart & Purser 1996) so, although unlikely because of their relatively low value, any of the four New Zealand species could be released as fry into their natural habitat. Similarly, release of fry for later harvest is theoretically possible for grey mullet, a species widespread in tropical and subtropical seas, where they are also farmed. Although such activities taking place over the next 10 years cannot be ruled out, anything large scale seems unlikely. Enhancement of blue cod populations may come about through the re-establishment of original seabed structure such as biogenic reefs where blue cod growth and survival appear to be high, and through the return of dredge oyster shell (Cranfield et al. 2001; Carbines & Jiang 2002).

ARTIFICIAL REEFS

Artificial reefs, which are one or more objects of natural or human origin deployed on the sea floor to influence mainly physical or biological processes, are increasingly being established around the world (Seaman & Jensen 2000; Coutin 2001). Reefs use either a single material or several in combination, with designs varying from simple block structures to huge, complex matrices and mixed-shape designs. They provide vertical complexity to the benthic environment and may be either assembled expressly as a reef or acquired after being used for another, usually unrelated, purpose (e.g., a vessel). Many artificial reefs are constructed of cement-based materials; it appears concrete has no lasting negative impact on the ecosystem, and even the use of solid residues from coal combustion appears to have negligible environmental effects (Sheng 2000).

There is a lot of interest worldwide in the use of artificial reefs in marine enhancement (for example, see papers from the "Fifth International Conference on Aquatic Habitat Enhancement" held in California in 1991; proceedings from the sixth and seventh meetings are yet to be published). Artificial reefs are constructed or placed for a great variety of reasons (Sheehy & Vik 1992; Grove et al. 1994; Pickering & Whitmarsh 1997; Seaman & Jensen 2000) including commercial and recreational seafood harvesting, sea angling, recreational viewing and diving, aquaculture, environmental restoration and protection, natural resource management, and scientific enquiry. The US National Oceanic and Atmospheric Administration annually evaluates 8000–10 000 proposals for development of coastal and estuarine habitats (Thayer 1992).

Determining whether a reef actually increases production or just attracts and concentrates marine species is crucial in assessing its success. If a reef merely aggregates the species, then it is best viewed as fishing gear (Lindberg 1997). Fish aggregating devices have been used to enhance both commercial and recreational fisheries, but these are clearly concentrating devices that take advantage of the schooling behaviour of pelagic fishes around floating objects (e.g., Higashi 1994).

New Zealand has been relatively slow in developing artificial reefs. Australia, for example, has many more (Sanders 1974; Pollard 1989; Coutin 2001). Well known ones in New Zealand are derelict vessels, scuttled deliberately or accidentally—for example the *Rainbow Warrior* off Matauri Bay and other vessels off Tutukaka, Hahei, and in the Marlborough Sounds. A few small artificial reefs have been developed and their biology monitored (e.g., Russell 1971, 1975; Graeme 1994). Concrete Reef Balls™ have been installed in Hawke Bay and near Auckland (Anon. 2000; English 2001) and there is interest in them elsewhere around the country to enhance fish stocks and for coastal stabilising purposes.

New Zealand is likely to see many more applications over the next 10 years for the creation of artificial reefs, such as that proposed for Mount Maunganui (Mead & Black 1999), and further vessel sinkings. Marina development, and port expansion such as that likely at Port Gisborne, are likely to bring with them proposals for the construction of reefs to compensate for the loss of natural reef features (Cheney et al. 1994). Other reefs may be much smaller, such as further reefballs.

Interest in the development of artificial reefs is likely to be highest near urban centres, particularly to cater for recreational fishing and diving; where water visibility is particularly good, for diving; within easy access of ports and launching facilities, for recreational fishers; or where particular fishery stocks such as paua can be enhanced, for commercial fishers. Therefore, in the near future there could be interest in installations in any but the most remote parts of the country, and in a variety of habitats—estuarine to open sea.

FERTILISING THE SEA

Habitat modification considered so far has been largely confined to sea-floor alteration. But animal growth is ultimately dependent on primary production, and in turn on the availability of dissolved nutrients, particularly nitrate, ammonia, phosphate, and silicate. For coastal waters eutrophication, mainly from land run-off and the disposal of human waste, rather than nutrient deficiency, has often been the issue. There are, however, instances where phytoplankton growth has depleted nutrient reserves, particularly nitrates, in surface waters and led to levels of primary production insufficient to support crops. This is most likely in enclosed waters under stratified summer conditions (Gall et al. 2000). In such instances the sea might be fertilised to raise the general level of productivity, and hence the growth of particular species. There is also interest in fertilising offshore waters, but usually for different reasons.

Although there is a considerable literature concerning the fertilisation of inland waters (e.g., Stockner & Hyatt 1984), there has been much less research directed at enriching coastal waters. Fertilisation may be through the addition of nutrient-rich agricultural waste waters, inorganic fertilisers, or solid organic materials. Perhaps the most significant recent coastal fertilisation experiment is the Norwegian research programme, Maricult. In this study of the potential to increase marine harvests by fertilising both pelagic and benthic ecosystems, small- to medium-scale fertilisation trials have taken place in both landlocked and coastal waters (Sakshaug et al. 1995), but the outcomes have yet to be reported.

There is considerable interest in offshore enhancement of primary production (Boyd et al. 2000). Ocean-fertilisation experiments have shown that when limiting trace elements (particularly iron in Pacific and southern waters) are added to the sea, there can be greatly increased primary production (Chisholm 2000). Although the main focus has been the prospect (not without controversy) of using ocean fertilisation to manipulate climate, the cultivation and enhancement of marine products is also of interest. Patents on ocean fertilisation have been issued to entrepreneurs (Chisholm 2000), with plans for a 8000 km^2 experiment afoot.

Deliberate fertilisation of New Zealand's coastal seas is most likely to be considered only for areas of intensive aquaculture cut off from the open sea and, at least over the next 10 years, only at a small to medium experimental scale. This could include, in particular, parts of Marlborough Sounds, but there are other potential areas such as Golden Bay and some northern harbours. The experimental fertilisation of waters within mussel farms with nutrients, and the seeding of phytoplankton cultured *in situ* and fed into the water flowing though the farm, are both being considered for Marlborough Sounds. However, no interest in the fertilisation of the offshore waters around New Zealand is expected within the next 10 years or so, except perhaps in further modest-scale, hypothesis-testing experiments.

DISCUSSION OF RELATED ISSUES

Fisheries enhancement brings challenges to managers of the New Zealand marine environment, both because management needs to be more intensive, requiring a good understanding of ecosystems, and because changes are necessary to the framework by which fisheries are managed. There will be a need for closer integration between the Fisheries Act 1996, which controls and manages fishing, and environmental planning affecting the marine habitat, the responsibility of regional councils under the Resource Management Act (RMA) 1991. At present, the right to catch fish in an area is mainly based on individual transferable quotas (ITQs) and fisheries management is therefore detached from the overall environmental management of the area. An ITQ gives a fisher the right to catch up to a limit, specified for each fisher as their quota holding, within a quota management area (QMA) (Anon. 1998; Office of the Parliamentary Commissioner for the Environment 1999). All fishers able to access a QMA can potentially harvest the product of enhancement and those enhancing the fishery are unable to exclude others. More intensive spatial management of fisheries will therefore be required if there is widespread enhancement, because those undertaking enhancement will usually want priority in harvesting the additional potential. Further, the environmental impact of any habitat manipulation and enhanced fishery will need careful attention. Aquaculture reform (Anon. 2001b) is moving towards an integrated approach to the marine environment as there are limits to how effectively case-by-case consideration can manage cumulative effects. The development of an Oceans Policy should lead to a more comprehensive coastal and marine planning framework (Anon. 2003: Oceans policy programme, http://www.oceans.govt.nz/policy/policyindex.html).

Artificial reefs in particular require approval under the RMA, either by way of resource consent or through the Regional Coastal Environment Plan. This means that the environmental effects of reefs must be assessed, including the impacts of the reef on other activities. Furthermore, if artificial reefs are to become more widespread it will be necessary in the coastal plan to consider their cumulative effects.

There are potentially negative impacts associated with the enhancement practices discussed. For all shellfish species, the collection and transferral of wild seed, particularly into new waterways, brings the risk of both reduced genetic diversity and of lowered resistance to disease for the new area in instances where the imported stock swamps the local one. The concerns are similar where there is seeding of hatchery spat, which are likely to come from just a few breeding adults, possibly not from the seeding area. There is also the possibility of distributing unwanted organisms far and wide, within spat, on them, or with them. Of particular concern is the spread of spores of the introduced macroalga *Undaria pinnatifida*, toxic algae cells, and in dredge oysters, the parasite *Bonamia exitiosus*. The laying out of young shellfish such as scallop spat over a wide area means that there may well be substrates later fished that would not otherwise have been disturbed.

For shellfish such as scallops the "decoupling" of sources of recruits from natural processes is of concern: there is high reliance on spat collections and little regard to maintenance of the physical and biological structure of the sea floor to sustain levels of natural larval recruitment. Where shellfish are transferred to other beds, there may be significant seabed disturbance and also a change in ecosystem balance of both the exhumed and enhanced beds. Further, protection by caging of newly seeded shellfish, or provision of artificial shelters, may disrupt natural physical and biological processes in the shellfish beds, in particular increasing siltation. Littering of the sea floor with artificial shelters and reefs, potentially causing unwanted or unpredictable changes in the ecosystem, are potential risks from enhancement of species such as paua and rock lobster.

The impacts of any seaweed enhancement are likely to be small because of their expected small scale but include seabed disturbance if there is clearing to allow growth of target seaweed, changes to the ecosystem balance of enhanced areas, and any protective caging disrupting natural processes and possibly leading to increased siltation.

For fish, potential risks of seeding include attraction of predators and hence increased levels of predation on other key species, undesirable interactions with other shallow coastal species, genetic and disease concerns where there is a limited range of seed sources, and genetic and disease issues where there is regional transfer.

Artificial reefs can be large and therefore have considerable impact on natural processes—biological and physical (Sheng 2000). They can slow currents, bring about sedimentation or scouring, increase turbidity, increase nutrients and so lead to algal blooms, bring about changes in water quality through sediment resuspension, cause upwelling, destroy nearby natural habitat by disintegration or movement, allow new species to establish, and increase predation of target species by harbouring predators. Many artificial reefs have moved, been altered or destroyed, or have disappeared (Bohnsack et al. 1997). Special care is needed where the elements of the reef may bring with them unwanted organisms. For example, in New Zealand a vessel to be submerged could introduce foreign organisms such as *U. pinnatifida*. Undesirable practices in the establishment of artificial reefs include the use of large explosive detonations to sink vessels, and the use of unstable or ineffective materials such as car bodies, fibreglass boat hulls, and washing machines (Bohnsack et al. 1997). It appears, however, that car tyres are suitable. With improvements in reef design and methods for securing them, tyres have become a widely accepted material for artificial reef construction in Australia and elsewhere (Branden et al. 1994). Indeed, artificial reefs may be a leading practical re-use for worn tyres (Candle 1985).

The possible negative impacts and issues of coastal fertilisation include eutrophication, particularly in enclosed waters, potentially leading to the destruction of the commonly owned resources such as fish and wild shellfish; a possible change in population structure of the phytoplankton, leading even to uncontrollable toxic blooms; other unpredictable shifts in the ecosystem balance; and increased sedimentation. MacKenzie (1996) and Buhl-Mortensen (1997) are concerned that such large-scale fertilisations as Maricult do not recognise the major differences between agriculture and the cultivation of the sea, that knowledge of marine ecosystems is limited and there is very restricted ability to control any effects, and that management should favour the environment where there is any uncertainty or doubt about negative effects.

CONCLUSIONS

We have referred to a variety of marine enhancement initiatives in New Zealand, actual and potential, often in the context of similar developments elsewhere. Perhaps the most significant potential enhancement activities not being undertaken in New Zealand to any extent at present, but common elsewhere, are: (1) for clam species, the seeding of hatchery-reared spat; and (2) the construction of artificial reefs and associated structures to enhance fish and shellfish populations.

There has been increased interest in marine enhancement in New Zealand in recent years and this attention is likely to continue over the next several. Interest will come from iwi and community, recreational, and commercial groups. This flows on from the successful Nelson scallop enhancement programme, encouraging results from other enhancement initiatives, a growing awareness of the need to rehabilitate the seabed if production is to be maintained, and the increasing momentum of marine enhancement initiatives internationally. Most interest will be in small-scale programmes, but some others are potentially large. It is not possible to be explicit about likely developments in customary enhancement over the coming 10 years. It is anticipated, however, that they will be relatively modest in scope and benign in nature, and will generally fit readily with other enhancement initiatives.

The species likely to be of most interest to enhancement over the next 10 years include scallops, dredge oysters, estuarine shellfish including cockles and pipi, toheroa, paua, rock lobster, certain seaweeds, snapper, and salmon. We will probably also see much wider use of artificial reefs in ecosystem development. Programmes could potentially take place the length and breadth of the country.

Precise assessment of any negative environmental impacts of enhancement initiatives is extremely difficult. Consequently, it is generally possible to do little more than signal concern over possible impacts. Broadly, these could include the transmission of disease, habitat disturbance, rampant increase in abundance, loss of ecological balance, increased numbers of predators, reduced numbers or size of wild fish, elimination of species, and reduced heterozygosity.

Marine enhancement will create new challenges to the management of marine resources, from both the coastal planning and legislative perspectives, as demands intensify for spatially smaller management areas.

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REFERENCES

Adams, N. M 1994: Seaweeds of New Zealand. An illustrated guide. Canterbury University Press.

Aiken, D. 1993: Bivalve culture in Chile. *World Aquaculture 24(4)*: 6–19.

Akroyd, J. M. 2002: Investigation into enhancement of toheroa (*Paphies ventricosa*) populations on a North Island west coast beach, New Zealand. Unpublished MSc (Appl.) thesis, Auckland University of Technology, New Zealand.

Ambrose, R. F. 1994: Mitigating the effects of a coastal power plant on a kelp forest community: rationale and requirements for an artificial reef. *Bulletin of Marine Science 55*: 694–708.

Anonymous 1998: New Zealand commercial fisheries: the atlas of area codes and TACCs, 1998/99. Tauranga, New Zealand, Clement and Associates Ltd.

Anonymous 2000: Reef balls, a positive payback. *The Havelock North Village Press, 23 March.*

Anonymous 2001a: Stock enhancement. *SEAFDEC Asian Aquaculture 23 (5 and 6)*: 17–33, 40, 41.

Anonymous 2001b: Aquaculture Reforms Papers A and B; Cabinet Finance, Infrastructure and Environment Committee Papers FIN (01) 218–219. New Zealand Government.

Anonymous 2002: Paua reseeding on Stewart Island. *Seafood New Zealand 10(4)*: 69–71.

Anonymous 2003: Press release by Moana Pacific Fisheries Ltd and Ports of Auckland at 1 May 2003.

Arbuckle, M.; Metzger, M. 2000: Food for thought. A brief history of the future of fisheries' management. Challenger Scallop Enhancement Company Ltd.

Babcock, R.; Keesing, J. 1999: Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. *Canadian Journal of Fisheries and Aquatic Sciences 56*: 1668–1678.

Babcock, R. C.; Kelly, S.; Shears, N. T.; Walker, J. W.; Willis, T. J. 1999: Changes in community structure in temperate marine reserves. *Marine Ecology Progress Series 189*: 125–134.

Bartley, D. M. 1999: Marine ranching: a global perspective. *In*: Howell, B. R.; Moksness, E.; Svåsand, T. *ed.* Stock enhancement and sea ranching. Oxford, Blackwell Science Ltd. Pp. 79–90.

Bartrom, A. A. 1991: The Coromandel scallop enhancement project 1987 to 1989. Internal report, Ministry of Agriculture and Fisheries, Auckland.

Best, E. 1929: Fishing methods and devices of the Maori. *Dominion Museum Bulletin 12*.

Blankenship, H. L.; Leber, K. M. 1997: A responsible approach to marine stock enhancement. *In*: Hancock, D. A.; Smith, D. C.; Grant, A.; Beumer, J. P. *ed.* Developing and sustaining world fisheries resources. The state of science and management. 2nd World Fisheries Congress. CSIRO Australia. Pp. 485–491.

Bohnsack, J. A.; Ecklund, A.; Szmant, A. M. 1997: Artificial reef research: is there more than the attraction-production issue? *Fisheries 22(4)*: 14–16.

Booth, J.; Jeffs, A.; Hooker, S.; Davies, P.; Zame, C. 1999: Commercial scale collections of young rock lobster for aquaculture. World Aquaculture '99 Conference, Sydney, 27 April–2 May 1999. (Abstract)

Boyd, P. W. and 34 others 2000: A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization. *Nature 407*: 695–702.

Branden, K. L.; Pollard, D. A.; Reimers, H. A. 1994: A review of recent artificial reef developments in Australia. *Bulletin of Marine Science 55*: 982–994.

Breen, P. A. 1994: Sustainable fishing patterns for geoduc clam (*Panopea zelandica*) populations in New Zealand. *New Zealand Fisheries Assessment Research Document 94/4*.

Briones-Fourzan, P.; Lozano-Alvarez, E. 2001: Effects of artificial shelters (casitas) on the abundance and biomass of juvenile spiny lobsters *Panulirus argus* in a habitat-limited tropical reef lagoon. *Marine Ecology Progress Series 221*: 221–232.

Buhl-Mortensen, L. 1997: Is large-scale cultivation of the marine production system ecologically and ethically sound? *Vann 2*: 154–162. (in Norwegian with English summary).

Bull, M. F. 1994: Enhancement and management of New Zealand's "southern scallop" fishery. Proceedings of the 9th International Pectinid Workshop, Nanaimo, B. C., Canada, April 22–27, 1993. Vol. 2, pp. 131–136.

Butler, M. J.; Herrnkind, W. F. 1997: A test of recruitment limitation and the potential for artificial enhancement of spiny lobster (*Panulirus argus*) populations in Florida. *Canadian Journal of Fisheries and Aquatic Sciences 54*: 452–463.

Candle, R. D. 1985: Scrap tires as artificial reefs. *In*: D'Itri, F. M. *ed.* Artificial reefs—marine and freshwater applications. Lewis Publishers, Chelsea, Michigan. Pp. 293–302.

Carbines, G.; Jiang, W. 2002: Foveaux Strait: how do changes in habitat affect blue cod? *Seafood New Zealand 10(7)*: 41–42.

Chandler, R. A.; Robinson, S. M. C.; Martin, J. D. 2001: Collection of soft-shell clam (*Mya arenaria* L.) spat with artificial substrates. *Canadian Technical Report of Fisheries and Aquatic Sciences 2390.*

Cheney, D.; Oestman, R.; Volkhardt, G.; Getz, J. 1994: Creation of rocky intertidal and shallow subtidal habitats to mitigate for the construction of a large marina in Puget Sound, Washington. *Bulletin of Marine Science 55*: 772–782.

Chisholm, S. W. 2000: Stirring times in the Southern Ocean. *Nature 407 (6805)*: 685–687.

Clarke, C. B. 2001: Growth and survival of *Haliotis iris* in northern New Zealand, with special reference to aquaculture. Unpublished MSc thesis, University of Auckland, New Zealand.

Coutin, P. C. 2001: Artificial reefs: applications in Victoria from a literature review. *Marine and Freshwater Resources Institute Report No. 31*.

Cranfield, H. J.; Carbines, G.; Michael, K. P.; Dunn, A.; Stotter, D. R.; Smith, D. J. 2001: Promising signs of regeneration of blue cod and oyster habitat changed by dredging in Foveaux Strait, southern New Zealand. *New Zealand Journal of Marine and Freshwater Research 35*: 897–908.

Cranfield, H. J.; Michael, K. P.; Doonan, I. J. 1999: Case study. Changes in the distribution of epifaunal reefs and oysters during 130 years of dredging for oysters in Foveaux Strait, southern New Zealand. *Aquatic Conservation*: *Marine and Freshwater Ecosystems 9*: 461–483.

Cranfield, H. J.; Michael, K. P.; Stotter, D.; Doonan, I. J. 1994: Distribution, biomass and yield estimates of surf clams off New Zealand beaches. *New Zealand Fisheries Assessment Research Document 94/1.* 27 p.

Cranfield, J.; Michael, K. 2002: Foveaux Strait: working towards a sustainable oyster fishery. *Seafood New Zealand 10(7)*: 45–46.

Cross, T. F. 2000: Genetic implications of translocation and stocking of fish species, with particular reference to Western Australia. *Aquaculture Research 31*: 83–94.

Curtin, L. 1972: Development of rock oyster farming in New Zealand. *In*: Pillay, T. V. R. *ed.* Coastal aquaculture in the Indo-Pacific region. Fishing News Books, Surrey. Pp. 384–393.

Dean, T. A.; Deysher, L. E. 1994: Kelp restoration and establishment techniques. *Bulletin of Marine Science 55*: 1333.

Doupé, R. G.; Lymbery, A. J. 2000: Workshop summary. Managing translocations of aquatic species. *Aquaculture Research 31*: 151–156.

English, P. 2001: Artificial reefballs put on fish-friendly growth spurt. *The New Zealand Herald 18 October.*

Gall, M.; Ross, A.; Zeldis, J.; Davis, J. 2000: Phytoplankton in Pelorus Sound: food for mussels. *Water & Atmosphere 8(3)*: 8–10.

Gerring, P. K.; Andrew, N. L.; Dunn, A. 2001: Assessment of *Pterocladia lucida* at Waihau Bay, New Zealand. *New Zealand Fisheries Assessment Report 2001/72.* 23 p.

Graeme, M. 1994: Rebuilding a boulder reef. *New Zealand Science Monthly 6(5)*: 5.

Grove, R. S.; Nakamura, M.; Kakimoto, H.; Sonu, C. J. 1994: Aquatic habitat technology innovation in Japan. *Bulletin of Marine Science 55*: 276–294.

Habib, G. 1989: Traditional Maori fishing rights and aquaculture in New Zealand. *In*: Proceedings of AQUANZ '88 a national conference on aquaculture. *New Zealand Fisheries Occasional Publication 4*: 80–83.

Hart, P. R.; Purser, G. J. 1996: Weaning of hatchery-reared greenback flounder (*Rhombosolea tapirina* Gunther) from live to artificial diets: effects of age and duration of the changeover period. *Aquaculture 145*: 171–181.

Herrnkind, W. F.; Butler, M. J.; Hunt, J. H. 1997: Can artificial habitats that mimic natural structures enhance recruitment of Caribbean spiny lobster? *Fisheries 22(4)*: 24–27.

Higashi, G. R. 1994: Ten years of fish aggregating device (FAD) design development in Hawaii. *Bulletin of Marine Science 55*: 651–666.

Hilborn, R. 1998: The economic performance of marine stock enhancement projects. *Bulletin of Marine Science 62*: 661–674.

Holland, R. C.; Jeffs, A. G. 2000: The status of aquaculture in New Zealand. *World Aquaculture 31(1)*: 24–27.

Hooker, S.; Redfearn, P. 1998: Preliminary survey of toheroa (*Paphies ventricosa*) populations on Ninety Mile Beach and possible impacts of vehicle traffic. Report to Northland Regional Council. NIWA Client Report AK98042.

Jeffs, A. 1995: The sustainable management and development of coastal and aquatic resources of Te Rarawa ki Hokianga. Phase three: development of the coastal and aquatic resources. The University of Auckland.

Jeffs, A.; Booth, J. 2001: Artificial shelters could enhance lobster fishery. *Seafood New Zealand 9(7)*: 43.

Jeffs, A. G.; Creese, R. G. 1996: Overview and bibliography of research on the Chilean oyster *Tiostrea chilensis* (Philippi, 1845) from New Zealand waters. *Journal of Shellfish Research 15*: 305–311.

Jeffs, A. G.; Creese, R. G.; Hooker, S. H. 1997: The potential for Chilean oysters, *Tiostrea chilensis* (Philippi, 1845), from two populations in northern New Zealand as a source of larvae for aquaculture. *Aquaculture Research 28*: 433–441.

Johnson, M. S. 2000: Measuring and interpreting genetic structure to minimize the genetic risks of translocations. *Aquaculture Research 31*: 133–143.

Kapuscinski, A. R.; Brister, D. J. 2001: Genetic impacts of aquaculture. *In*: Black, K. D. *ed.* Environmental impacts of aquaculture. Sheffield Academic Press, Sheffield. Pp. 128–153.

Keogh, J. A.; Bremner, G.; Frazer, A. W. J.; Fletcher, D. J. 1997: Effects of treatment, site and time of reseeding on survival and growth in the Bluff oyster, *Tiostrea chilensis* (Bivalvia: Ostreidae) Philippi 1845. *Journal of Shellfish Research 16*: 267–268.

Kington, S. W. 1999: Factors influencing the on-growing and restocking of *Jasus edwardsii*. Unpublished MSc thesis, University of Auckland, New Zealand.

Liao, I. C. 1999: How can stock enhancement and sea ranching help sustain and increase coastal fisheries? *In*: Howell, B. R.; Moksness, E.; Svåsand, T. *ed*. Stock enhancement and sea ranching. Blackwell Science Ltd., Oxford. Pp. 132–149.

Lindberg, W. J. 1997: Can science resolve the attraction-production issue? *Fisheries 22(4)*: 10–13.

McCormick, T. B.; Herbinson, K.; Mill, T. S.; Altick, J. 1994: A review of abalone seeding, possible significance and a new seeding device. *Bulletin of Marine Science 55*: 680–693.

MacKenzie, D. 1996: Norway's fish plan 'a recipe for disaster'. *New Scientist 13 January*: 4.

McShane, P. E. 1995: Enhancement options for the Southland paua fishery (PAU 5). A report to PAU 5 quota holders. Internal report, MAF Fisheries Greta Point, Wellington, New Zealand.

McShane, P. E. 1997: A summary of commercial catch data and biological information for kina (*Evechinus chloroticus*). *New Zealand Fisheries Assessment Research Document 97/16*. 7 p.

McShane, P. E.; Black, K. P.; Smith, M. G. 1988: Recruitment processes in *Haliotis rubra* (Mollusca: Gastropoda) and regional hydrodynamics in southeastern Australia imply localized dispersal of larvae. *Journal of Experimental Marine Biology and Ecology 124*: 175–203.

Manning, R. B. 1985: *In vivo* settlement of the green-lipped mussel (*Perna canaliculus*) on natural and artificial substrates. Unpublished MSc thesis, University of Auckland, New Zealand.

Mead, S. 1996: Fertilization success, sustainable management and commercial development of the New Zealand sea urchin, *Evechinus chloroticus*. Unpublished MSc thesis, University of Auckland, New Zealand.

Mead, S.; Black, K. 1999: A multipurpose, artificial reef at Mount Maunganui Beach, New Zealand. *Coastal Management 27*: 355–365.

Mercer, S. 1986: Outplanting paua—the first field trials. *Shellfisheries Newsletter 31*: 8–9.

Ministry for Maori Development 1993: Customary fisheries—philosophy and practices, legislation and change.

Morrison, M. A.; Browne, G. N. 1999: Intertidal shellfish population surveys in the Auckland region, 1998–99, and associated yield estimates. *New Zealand Fisheries Assessment Research Document 99/43*. 21 p.

Mottet, M. G. 1985: Enhancement of the marine environment for fisheries and aquaculture in Japan. *In*: D'Itri, F. M. *ed.* Artificial reefs—marine and freshwater applications. Lewis Publishers Inc, Chelsea, Michigan. Pp. 13–112.

Munro, J. L.; Bell, J. D. 1997: Enhancement of marine fisheries resources. *Reviews in Fisheries Science 5*: 185–222.

Naylor, R. 2002: Enhancing paua fisheries. *Fisheries and Aquaculture Update 5*: 6.

Naylor, R.; Andrew, N. 2001: Paua—is the current size limit always appropriate? *Seafood New Zealand 9(6)*: 33.

Naylor, R.; Gerring, P. 2001: Interaction between paua and kina. *Water & Atmosphere 9(2)*: 16–17.

Nelson, W. A.; Conroy, A. M. 1989: Effect of harvest method and timing on yield and regeneration of karengo (*Porphyra* spp.) (Bangiales, Rhodophyta) in New Zealand. *Journal of Applied Phycology 1*: 277–283.

Nesbit, G. J. 1999: Reseeding and hatchery potential of *Pecten novaezelandiae* and effects of recreational harvesting. Unpublished MSc thesis, University of Auckland, New Zealand.

Nonaka, M.; Fushimi, H.; Yamakawa, T. 2000: The spiny lobster fishery in Japan and restocking. *In*: Phillips, B. F.; Kittaka, J. *ed.* Spiny lobsters: fisheries and culture. Oxford, Blackwell Science. Pp. 221–242.

Notman, P.; Naylor, R. 2000: Enhancing paua populations. *Seafood New Zealand 8(1)*: 28–29.

Office of the Parliamentary Commissioner for the Environment 1999: Setting course for a sustainable future. The management of New Zealand's marine environment.

Oliver, M.; Stewart, R.; MacDiarmid, A.; Gardner, C.; Mills, D. 2002: Behaviour of *Jasus edwardsii* reared in captivity. *The Lobster Newsletter 15(1)*: 9–11.

Osumi, K. 1999: Stock enhancement and habitat association of juvenile paua (*Haliotis iris*) in northeastern New Zealand. Unpublished MSc thesis, University of Auckland, New Zealand.

Pickering, H.; Whitmarsh, D. 1997: Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy. *Fisheries Research 31*: 39–59.

Pickering, T. D. 1989: Farming the red seaweed *Gracilaria sordida* in New Zealand. *In*: Proceedings of AQUANZ '88 a national conference on aquaculture. *New Zealand Fisheries Occasional Publication 4*: 68–70.

Pollard, D. A. 1989: Artificial habitats for fisheries enhancement in the Australian region. *Marine Fisheries Review 51*: 11–26.

Poole, R. 1998: Hatchery rearing of the geoduck clam (*Panopea abrupta*). *Clam and Oyster Farming, 1998*: 50–51.

Poortenaar, C.; Hooker, S.; Sharp, N. 1999: Where are we with kingfish aquaculture? *Aquaculture Update 23*: 9–10.

Redfearn, P. 1974: Biology and distribution of the toheroa, *Paphies (Mesodesma) ventricosa* (Gray). *Fisheries Research Bulletin No. 11*.

Redfearn, P. 1982: Larval shell development of the toheroa, *Paphies ventricosa* (Gray, 1843) (Mactracea: Mesodesmatidae). *New Zealand Journal of Marine and Freshwater Research 16*: 241–252.

Roberts, R. D.; Kawamura, T.; Takami, H. 1999: Abalone recruitment—an overview of some recent research in New Zealand, Australia and Japan. *Bulletin of the Tohoku National Fisheries Research Institute 62*: 95–107.

Rogers-Bennett, L. 2000: Evaluating stocking as an enhancement strategy for the red sea urchin, *Strongylocentrotus franciscanus*: depth-specific recoveries. *In*: Barker, M. *ed.* Echinoderms 2000. Swets & Zeitlinger, Lisse. Pp. 527–531.

Russell, B. 1971: Artificial reef. *Dive South Pacific Underwater Magazine 11(3)*: 16–18.

Russell, B. C. 1975: The development and dynamics of a small artificial reef community. *Helgolander Wissenschaftliche Meeresuntersuchungen 27*: 298–312.

Sakshaug, E.; Olsen, Y.; Hoell, E. 1995: Maricult research programme: fertilising marine ecosystems to harvest more. *Council Meeting of the International Council for the Exploration of the Sea, Aalborg, 21–29 September 1995*.

Sanders, M. J. 1974: Artificial reefs in Australia. *In*: Proceedings of an international conference on artificial reefs. Texas A&M University, Texas.

Schiel, D. R. T. 1989: Species enhancement in the natural environment. *In*: Proceedings of AQUANZ '88 a national conference on aquaculture. *New Zealand Fisheries Occasional Publication 4*: 56–59.

Schiel, D. R. 1992: The enhancement of paua (*Haliotis iris* Martyn) populations in New Zealand. *In*: Shepherd, S. A.; Tegner, M. J.; Guzman del Proo, S. A. *ed.* Abalone of the world; biology, fisheries and culture. Oxford, Fishing News Books. Pp. 474–484.

Schiel, D. R. 1993: Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. *Marine Ecology Progress Series 97*: 167–181.

Seaman, W.; Jensen, A. C. 2000: Purposes and practices of artificial reef evaluation. *In*: Seaman, W. *ed.* Artificial reef evaluation with application to natural marine habitats. New York, CRC Press. Pp. 1–19.

Sheehy, D. J.; Vik, S. F. 1992: Developing prefabricated reefs: an ecological and engineering approach. *In*: Thayer, G. W. *ed.* Restoring the nation's marine environment. NOAA, Maryland Sea Grant. Pp. 543–581.

Sheng, Y. P. 2000: Physical characteristics and engineering at reef sites. *In*: Seaman, W. *ed.* Artificial reef evaluation with application to natural marine habitats. New York, CRC Press. Pp. 51–94.

Stewart, M. J.; Creese, R. G. 1998: Restoration of the New Zealand little necked clam, *Austrovenus stutchburyi*. *Journal of Shellfish Research 17*: 1313.

Stewart, M. J.; Creese, R. G. 2002: Transplants of intertidal shellfish for enhancement of depleted populations: preliminary trials with the New Zealand little neck clam. *Journal of Shellfish Research 21*: 21–27.

Stewart, R.; Oliver, M.; MacDiarmid, A.; Gardner, C.; Mills, D. 2002: Enhancing reefs with juvenile lobsters. *Fisheries and Aquaculture Update 5*: 1.

Stockner, J. G.; Hyatt, K. D. 1984: Lake fertilization: state of the art after 7 years of application. *Canadian Technical Report, Fisheries and Aquatic Sciences 1324*.

Street, B. 1995: Oyster enhancement trials in Foveaux Strait. *Seafood New Zealand 3(9)*: 32–33.

Street, R. J.; Crowther, G. S.; Kirkman, J. S. 1973: Oyster shell return experiment—Foveaux Strait 1970–1971. *Fisheries Technical Report 107*.

Tait, M. 1997: Snapper culture. NIWA Report WLG97/35.

Tegner, M. J. 1992: Brood-stock transplants as an approach to abalone stock enhancement. *In*: Shepherd, S. A.; Tegner, M. J.; Guzman del Proo, S. A. *ed.* Abalone of the world; biology, fisheries and culture. Oxford, Fishing News Books. Pp. 461–484.

Thayer, G. W. 1992: The science of restoration: status and directions. *In*: Thayer, G. W. *ed.* Restoring the nation's marine environment. NOAA, Maryland Sea Grant. Pp. 1–8.

The Bluff Oyster Enhancement Company 1995: Bluff oyster larvae—a by-product from the fishery. *Seafood New Zealand 3(9)*: 33–34.

The New Zealand Paua Management Company 2000: Experimental enhancement of paua: fishery management area PAU 5B (Stewart Island). A preliminary discussion document.

Thomson, G. M.; Anderton, T. 1921: History of the Portobello Marine Fish-hatchery and Biological Station. *Dominion of New Zealand Board of Science and Art Bulletin 2*.

Tong, L. J.; Moss, G. A. 1992: The New Zealand culture system for abalone. *In*: Shepherd, S. A.; Tegner, M. J.; Guzman del Proo, S. A. *ed.* Abalone of the world; biology, fisheries and culture. Oxford, Blackwells. Pp. 583–591.

Tong, L. J.; Moss, G. A.; Illingworth, J. 1987: Enhancement of a natural population of the abalone, *Haliotis iris*, using cultured larvae. *Aquaculture 62*: 67–72.

Travis, J.; Coleman, F. C.; Grimes, C.B; Conover, D.; Bert, T. M.; Tringali, M. 1998: Critically assessing stock enhancement: an introduction to the Mote Symposium. *Bulletin of Marine Science 62*: 305–311.

Tunbridge, B. R. 1967: Toheroa survey—Wellington beaches—May 1965. *Fisheries Technical Report 21*.

Tunbridge, B. R. 1968: The Tasman Bay scallop fishery. *Fisheries Technical Report 18*.

Turner, S.; Cummings, V.; Hewitt, J. 1998: Guidelines for community shellfish restoration and enhancement projects. *NIWA Information Series 4*.

Unwin, M. J.; Davis, S. F.; Hall, M. C. (*Comp.*) 1991: Salmon towards 2000: proceedings of a conference held at Addington Raceway, Christchurch, 27–28 October 1990. *New Zealand Freshwater Fisheries Report 129*.

Waugh, G. D. 1973: Fish and fisheries. *In*: Williams, G. R. *ed.* The natural history of New Zealand. An ecological survey. Wellington, A. H. and A. W. Reed. Pp. 251–284.

Welcomme, R. L.; Bartley, D. M. 1998: Current approaches to the enhancement of fisheries. *Fisheries Management and Ecology 5*: 351–382.